

Intermittency Management and High Penetration Renewables

Nicholas W Miller

James P Lyons

GE Energy

CEC Workshop February 3, 2005

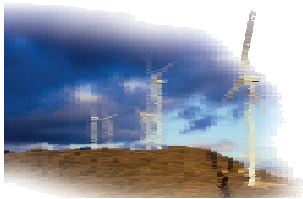


GE imagination at work

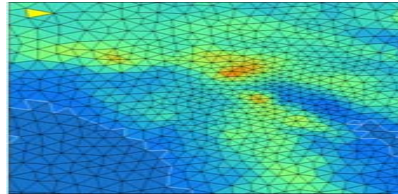


Power Generation Firming & Smoothing

Slow - Generation Firming



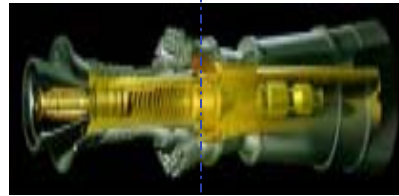
Wind



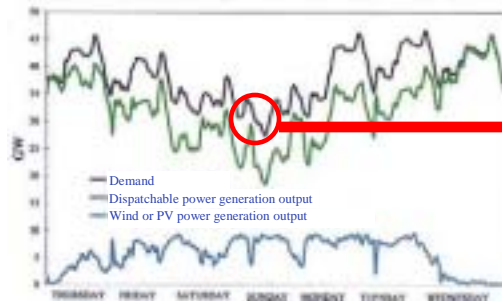
Advanced Forecasting



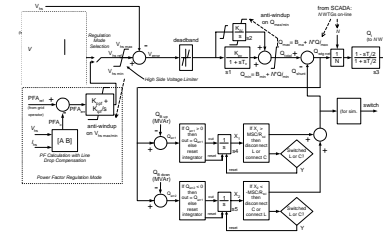
Storage



Advanced Generation



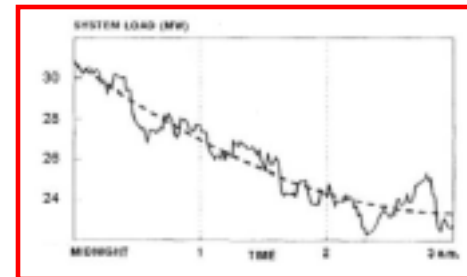
Fast - Generation Smoothing



Advanced Power Controls



Active Demand Participation



A full suite of technologies will enable high renewables penetration:
Forecasting + Controls + Storage + Advanced GT + Active Load Control

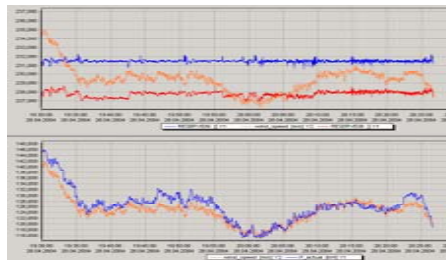
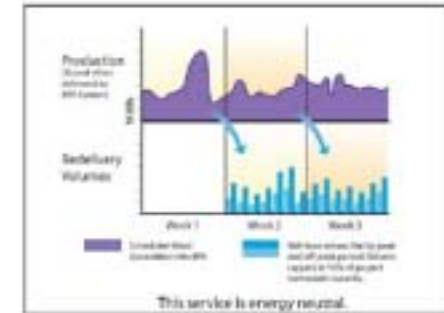
Technologies



James Bay Canada – 18 GW Hydro

Hydro Energy Storage

- Reservoirs 'virtual' energy storage
- BPA wind storage & shaping - 0.6 cents/KWh
- Pumped-hydro storage, var speed pumping req'd



GE WFMS Voltage Control @ Colorado Green

Controls

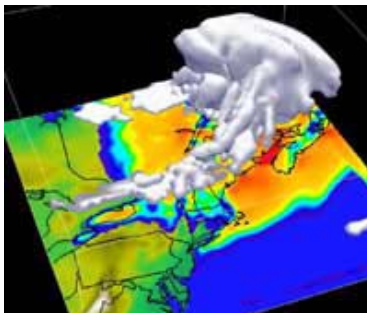
- Wind farm level supervisory control
- Distributed real & reactive power control
- Voltage, VAR, & PF control
- Power curtailment, ramp rates

High Efficiency GT

- Simple cycle for fast tracking response
- High efficiency 46%, 40% at ½ load

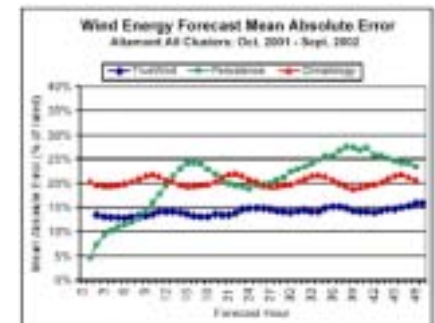


GE LMS100 High Efficiency Simple Cycle Gas Turbine



Advanced Forecasting

- Local statistical model + 3D meso-scale climatology model
- 10-15% MAE for day-ahead and 5-10% for 6 hr ahead
- Cal ISO – unbiased hourly, daily forecasts – settlement monthly at average rate



GE 1.5 MW Turbine Family



| 1.5 Wind Turbines | | | | |
|--------------------------|-------------|--------------|-------------|---------------|
| | 1.5e | 1.5se | 1.5s | 1.5sle |
| <i>Frequency</i> | 60Hz | 50/60Hz | 50/60Hz | 50/60Hz |
| <i>Wind Regime</i> | IEC TC Ia+ | IEC TC Ib | IEC TC IIa | TC III/s |
| <i>Rotor Diameter</i> | 65m | 70.5m | 70.5m | 77m |
| <i>Rated Power</i> | 1.5 MW | 1.5 MW | 1.5 MW | 1.5 MW |
| <i>Hub Heights</i> | 65m | 52-65m | 65-85m | 61-85m |
| <i>Speed Range</i> | 11-22 rpm | 11-22 rpm | 11-22 rpm | 10-20 rpm |

GE Developments

- 2500 Turbines Installed
- Reliability Growth
- COE Reduction, Global Sourcing
- Extended Operations – Temp, IEC TC I/II

GE 3.6 MW Wind Turbine

GE WIND - 3.6 Offshore



Main Data:

- Tower options: 100 - 140m
(328 to 459 ft)
- Rotor diameter: 104 m (341 ft)
- Generator capacity: 3600 kW
- Control: Pitch
- Rotor speed: 8.5 – 15.5 Rpm
- Swept area: 7854 m²

System Operation & Wind Variability

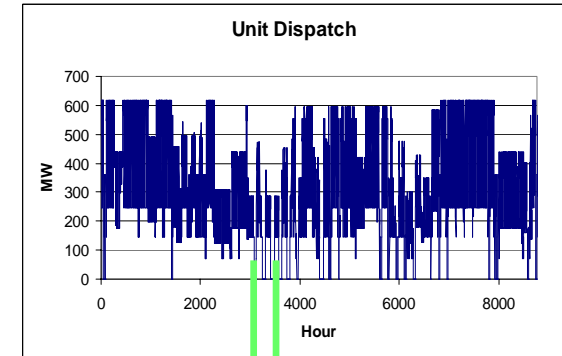
Slower ->

*Operational/
Cost Regime*

Spinning Reserve
(Day Ahead Scheduling)

*Technology
Advancements*

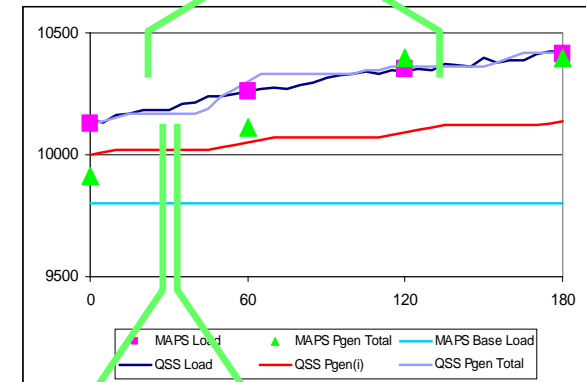
Multiday forecasting –
participation in SMD



Time Scale

Load Following
(5 Minute Dispatch)

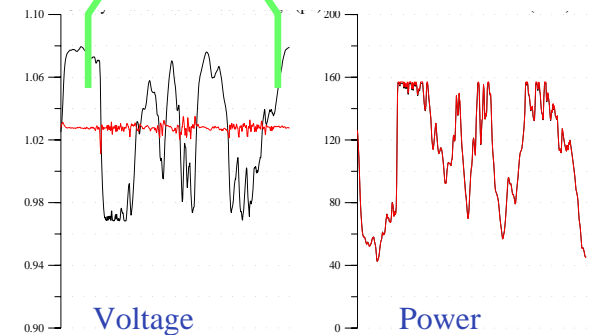
Short-term forecasting and wind farm active power management



<- Faster

Frequency & Tie-line
Regulation (Seconds)

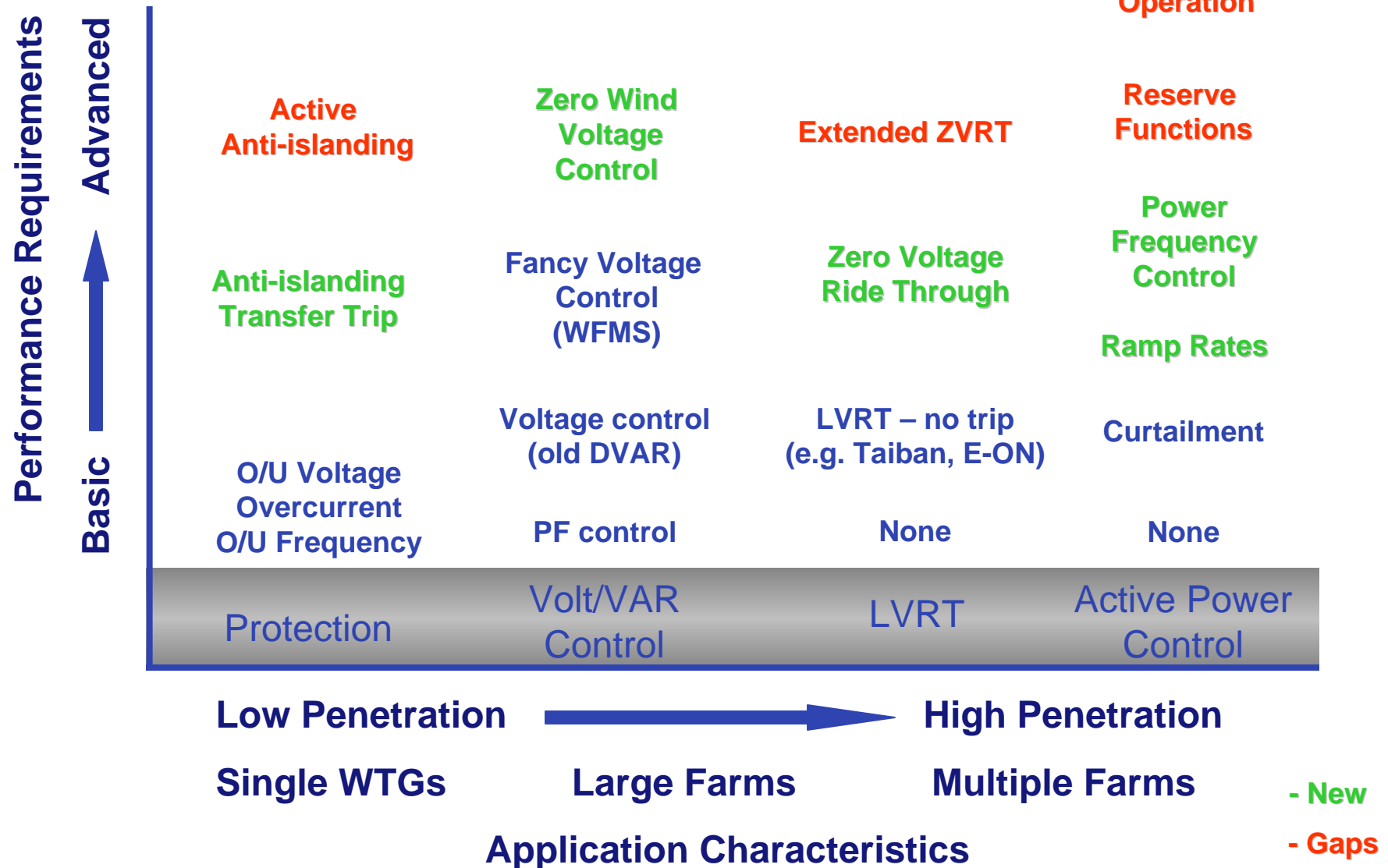
WTG level active and
reactive power controls



600 seconds



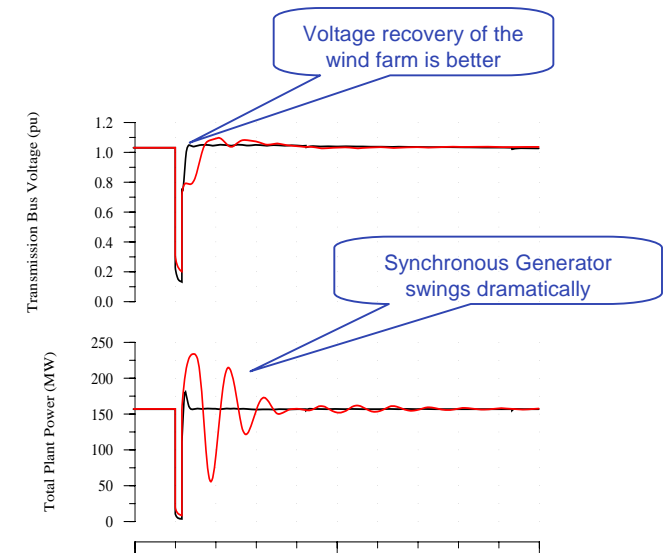
Grid Features Evolution



Interconnection Issues

Dynamic Performance

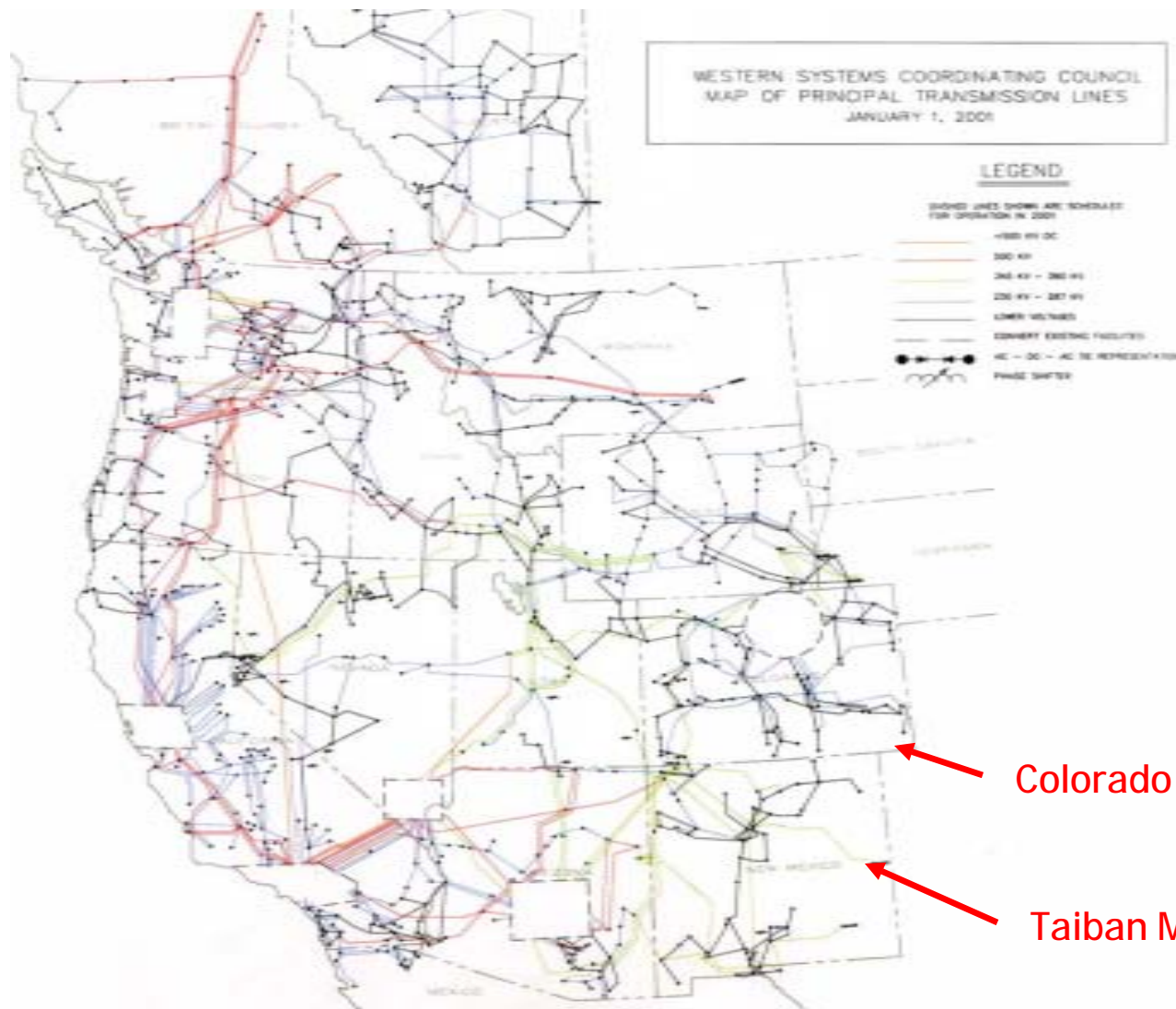
- Stability
 - Maintaining Synchronism
 - Damping
- Fault Tolerance/Low-Voltage Ride-Through (LVRT)
- Voltage Regulation
 - Steady-state reactive power capability
 - Dynamic voltage response
 - Flicker
- Variable Power



Problems are particularly challenging
for large radially connected projects with
low short-circuit ratio systems

Application Examples

Recent projects
in Western US
illustrate
challenges and
controls
needed for
successful
system
integration



Colorado Green 162 MW

Taiban Mesa 204 MW

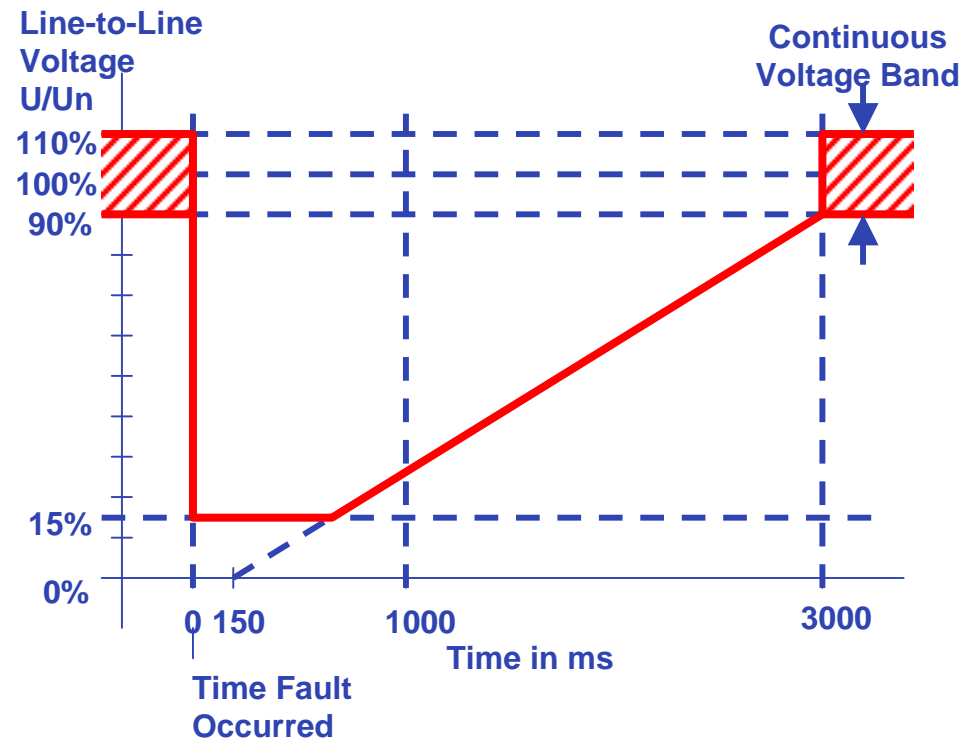
Low Voltage Ride-Through Factory Test



LVRT Capability

Rapidly Evolving Grid Codes

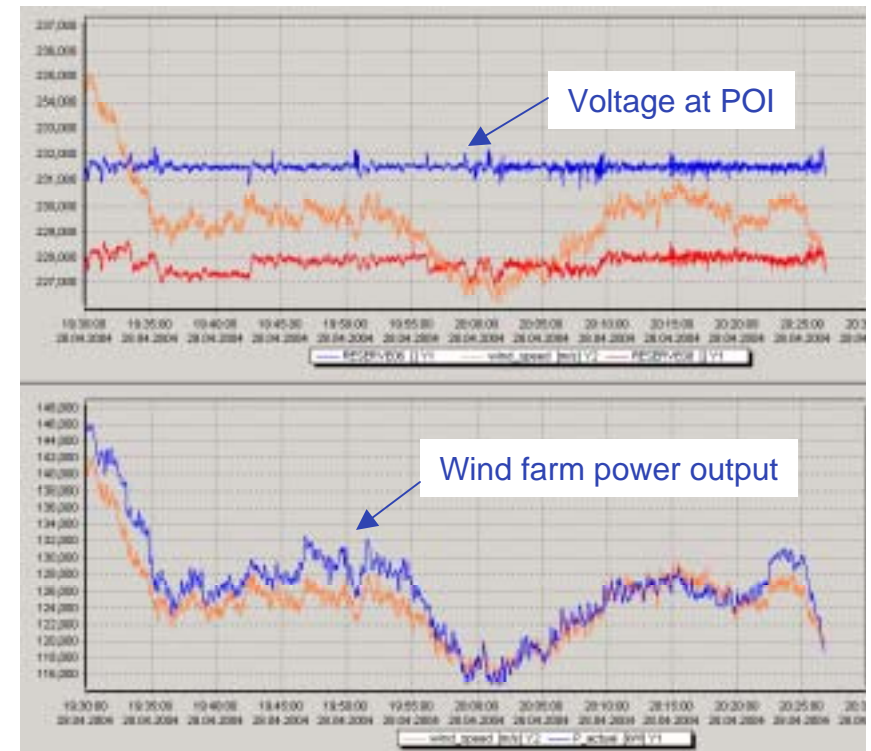
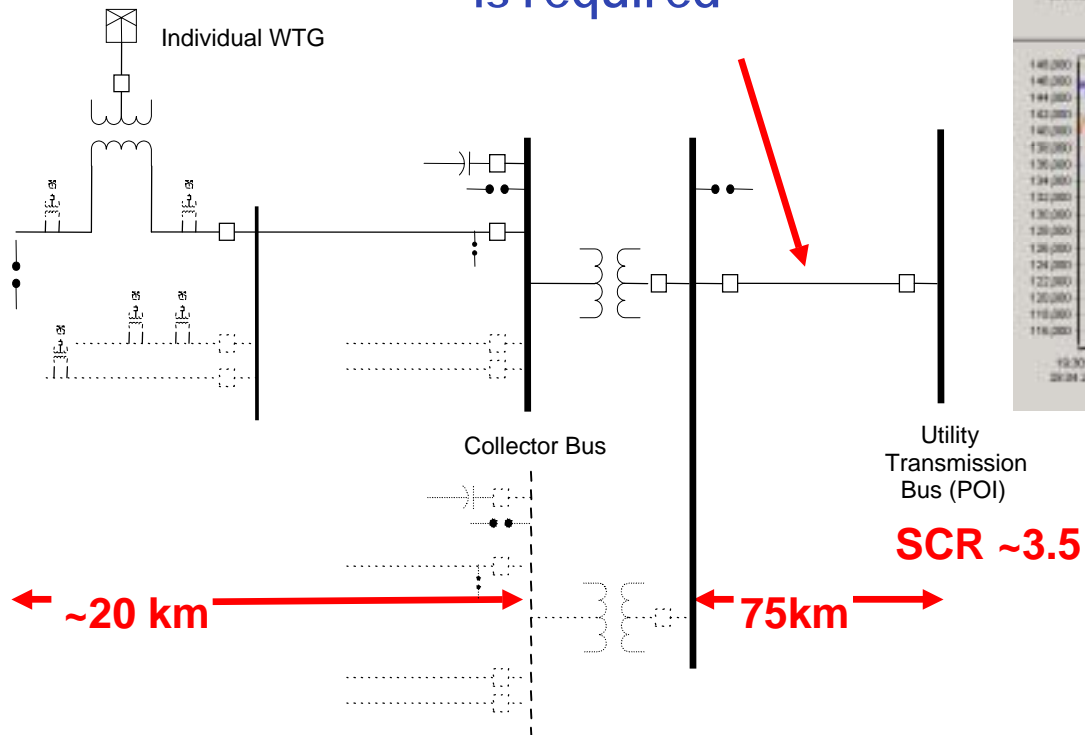
- Success of wind is driving sweeping changes
- New ride through capabilities are engineered to meet global needs
- Designed for faults on any combination of phases
- Zero voltage ride through offering imminent



Colorado Green Measurements

April 28, 2004

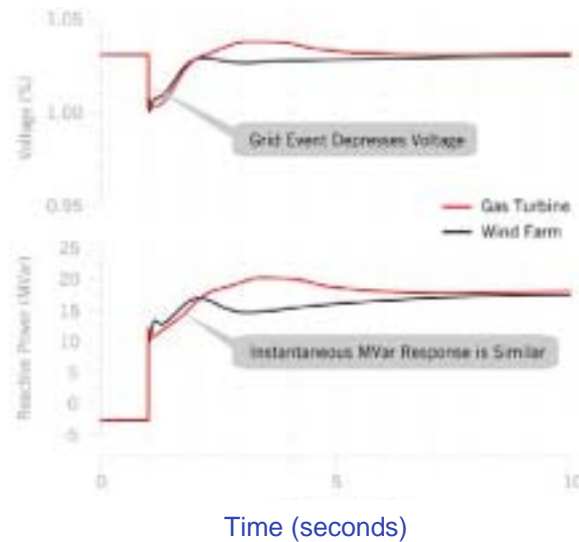
Compensation for long cable runs including charging is required



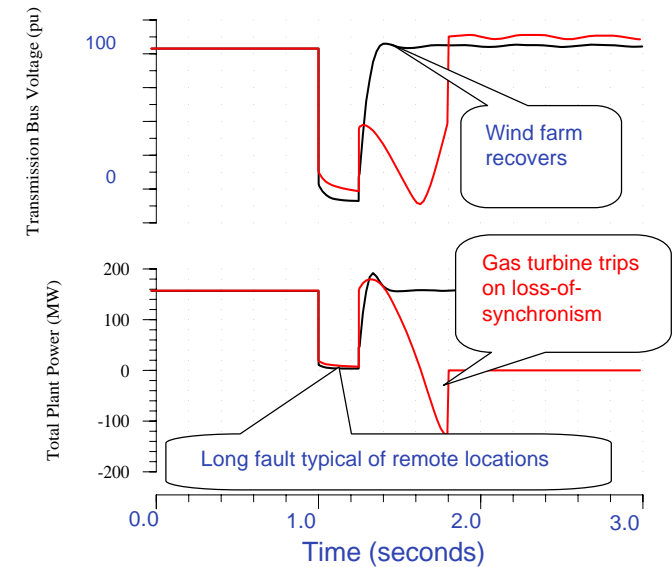
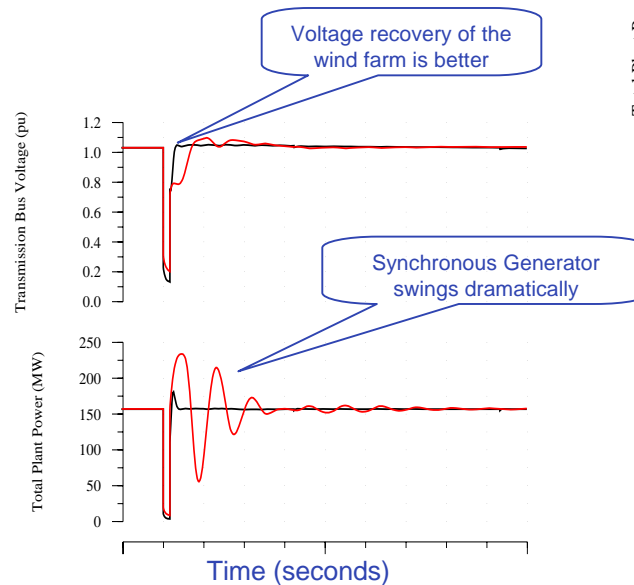
Wind Turbine Transient Response

GE Wind farms can provide similar voltage regulation to that of conventional synchronous generators.

In fact, GE wind farms will survive some disturbances that trip conventional synchronous generators.



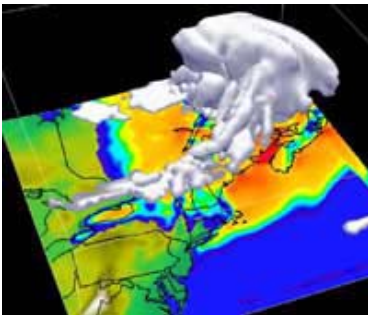
GE Wind farms are more stable than conventional synchronous generators.



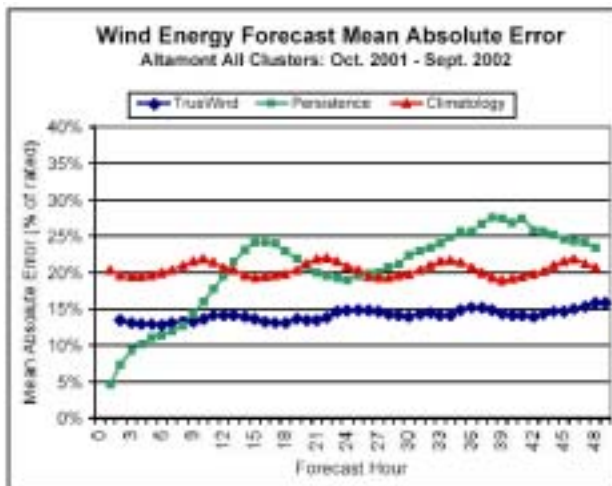
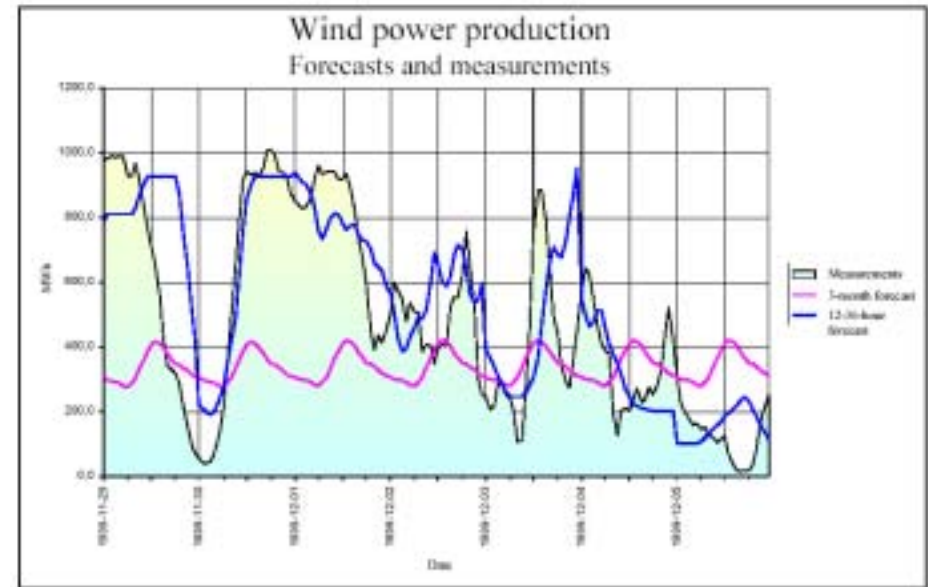
Wind Forecasting

Eltra, Denmark - 2000 Study

- 1.9GW onshore farms, 16% consumption
- 3.4TWh produced, 1.3TWh miscalculated (38%)
- Climatology-based forecast, inaccuracies up to 800MW
- \$12M imbalance payments (0.3c/kWh)



Advanced forecast using a combination of local statistical models, and 3D meso-scale climatology



Current State-of-the-Art

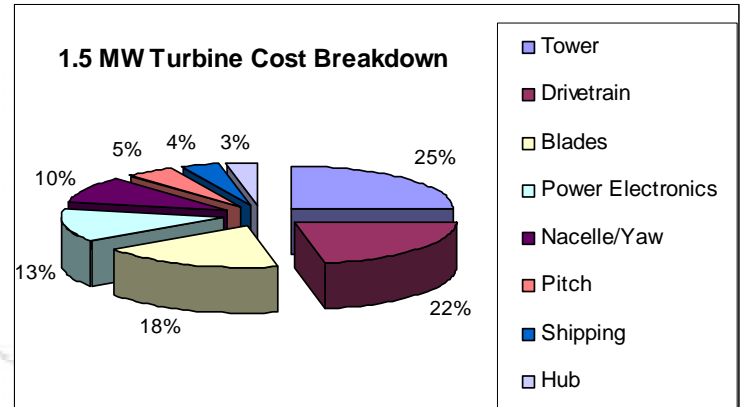
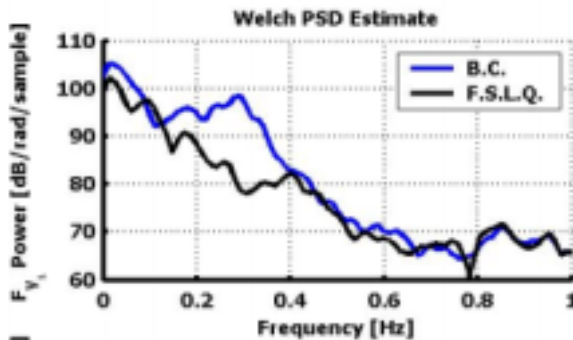
- **Local statistical model + 3D climatology model** - 10-15% mean abs error for day-ahead and 5-10% error for 6 hr ahead forecasts
- 2005 regulations in **Spain** provide:
 - Penalties for >20% error on 24hr production forecast
 - Incentives for <10% error over rolling 4hr forecast
- 2003 **Cal ISO** regulations – unbiased hourly, daily forecasts – settlement monthly for net deviations at average rate
- **Utilities** need short (<6h), med (24-36h) and long term (>72h) forecasts

What's Next Lighter, Smarter Turbines

Blades: hybrid carbon fiber, 2x stiffness, 25% weight reduction



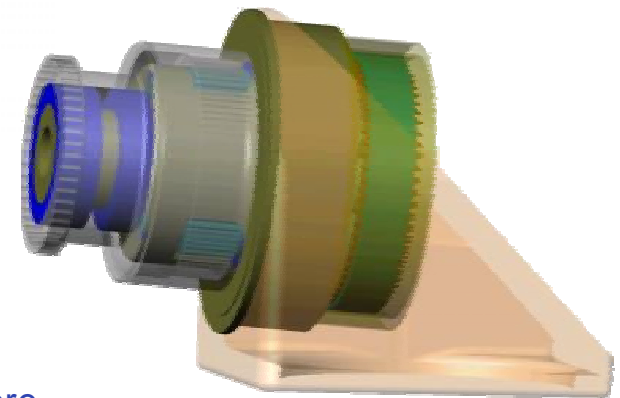
Controls: load mitigation, independent pitch, & damping



Costs: Towers, Drivetrain, & Rotor dominate component costs – 65%

Next Gen Turbines

- Larger relative swept area
- Rotor diameters > 120m
- 3+ MW land based, 5+ MW offshore
- Full power conversion
- Lighter towers to 120m
- Intelligent, light, compliant



Drivetrain: compact, high efficiency, minimal gearing

Conclusions

Transmission owners and operators have legitimate concerns about potential adverse impacts of wind generation on the grid.

Many of those concerns are well addressed by the latest wind technologies.

Proper system engineering and cooperation with the host grid owners and operators will limit problems for individual projects.

Wind technology must continue to evolve to meet an expanding spectrum of power system needs.